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Evaluation of an Activated Sludge Secondary Clarifier Distributed Inlet

Stamford Water Pollution Control Facility, CT

Prepared for

Environmental Protection Agency, Cincinnati, OH

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by

Jeannette A. Semon
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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. The complexity of our environment and the interplay of its components require a concentrated and integrated attack on pollution problems.

Research and development is the necessary first step in problem solution and involves defining the problem, measuring its impact and searching for solutions. The Water Engineering Research Laboratory develops new and improved technology and systems to 1) prevent, treat and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, 2) preserve and treat public drinking water supplies, and 3) minimize the adverse economic, social, health and aesthetic effects of pollution. This publication is one of the products of the Laboratory's research program and provides a vital communication link between the researcher, the design engineer and the user community.

This project demonstrated the performance of a unique inlet structure intended to improve the vertical and horizontal distribution of mixed liquor in a activated sludge secondary clarifier. The overall goal of this project was to provide a better understanding of how inlet structures affect the hydraulic characteristics and performance of activated sludge secondary clarifiers. This information will enhance the knowledge of the designers, manufacturers and operators of the units.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

Secondary clarifiers are crucial to the overall performance of the activated sludge process. Research over the last 40 years has indicated that density currents are factors which degrade clarifier performance when not considered in design. However, current design of most center-feed, perpherial overflow clarifiers fail to adequately control these influences. The purpose of this document is to report the results of a full-scale demonstration project which evaluated a unique inlet designed to distribute flow in this type of secondary clarifier equally both horizontally and vertically and prevent the formation of density currents.

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CONVERSION TABLE

m	x 3.281	=	ft
mm	x 3.937×10^{-2}	=	in.
m^3/d	x 2.642×10^{-4}	=	mgd
$m^3/m^2 \cdot d$	x 24.55	=	gpd/ft^2

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I wish to acknowledge the hard work, time and effort put forth on this project by Mr. Robert M. Crosby, Crosby and Associates, Inc. and Mr. Charles S. Applegate, Rexnord/EnviroEnergy Technology Center. Their creativity, motivation and strong desire to improve the design and operation of secondary clarifiers allowed this project to be conceived and evaluated.

Mr. Brian D. Wilson and Dr. Rudy J. TeKippe peer reviewed this report and offered numerous suggestions that have helped improve it. Their time and effort is appreciated.

SECTION 1

INTRODUCTION

Activated sludge secondary clarifiers provide the necessary conditions that allow the gravity separation of the activated sludge from the treated wastewater before discharge. Conditions considered optimal in the clarifier are those where the horizontal velocities of the flow through the clarifier are uniformly distributed both horizontally and vertically with no short circuiting. These conditions are a key assumption in the development of Camp's (1) sedimentation theory which extends the work of Hazen (2) where only clarifier surface area controls performance. Current design criteria (3) for clarifiers have similar requirements.

DENSITY CURRENTS IN ACTIVATED SLUDGE SECONDARY CLARIFIERS

Creating these optimal conditions in practice has been difficult if not impossible. Camp (1) cannot create uniform flow conditions in a laboratory clarifier set up to verify his theory. This clarifier has orifice walls at the inlet and outlet end. Uniform flow is observed near these orifice walls, but the flow is never uniform throughout the entire clarifier. He finds that the brine solution used as a tracer to study short circuiting influences the flow pattern in the clarifier. After the brine solution passes the influence of the inlet orifice wall, it drops to the bottom and proceeds along the bottom in a thin layer to the outlet end. Camp also finds that a temperature difference of 0.1°C within the clarifier and the resultant changes in water density disrupts the flow pattern. He theorizes that other causes of density changes such as the presence of soluble substances and suspended particles in the water will have a similar affect. Gould (4) reports on an evaluation of full-scale rectangular activated sludge secondary clarifiers. He notes the different settling behavior of activated sludge from that observed in primary clarifiers. It creates a current along the bottom of the tank away from the influent end. When this current reaches the far wall, it is forced upward and reverses its direction across the top of the tank.

Anderson (5) first uses the term density current to describe this phenomenon in activated sludge secondary clarifiers and notes that they have a significant impact on performance. He adapts the term from a similar phenomenon found when silting occurs in reservoirs. Density currents are defined as a gravity flow produced in one fluid by another fluid of slightly greater density seeking the lower level. Anderson considers the mixed liquor to act as a liquid of greater density causing it to plunge to the bottom of the tank and flow along the bottom until it hits some obstruction, usually the wall of the tank. It then flows upward inducing a current in the reverse

direction in the upper portion of the tank back towards the influent. He finds density currents in activated sludge secondary clarifiers at five different locations, but not in the one primary clarifier evaluated.

Several authors acknowledge the presence of density currents. Crosby (6) identifies them in seven different activated sludge secondary clarifiers using innovative dye tracer techniques as does Mazurczyk et al. (7) using radioactive tracer techniques. Stukenberg (8) acknowledges this pattern of flow as well as Parker (9).

The exact cause of these flow patterns is questioned by several authors. Murphy (10) concludes that the momentum of the influent flow establishes these flow patterns and not a difference in density between the influent and the basin contents. He bases this conclusion on the observation that even the addition of a small concentration of dye tracer to the influent of a laboratory clarifier causes the development of these flow patterns. Wouda et al. (11), however, find that suspensions with densities of 1.0002, as compared to water, produce velocities in a laboratory scale tank significantly in excess of the theoretical nominal flow through velocity. The magnitude of the velocities increases with increased densities of the influent.

CONTROLLING THE IMPACT OF DENSITY CURRENTS ON PERFORMANCE

Eckenfelder and Melbinger (12) state that both the settling properties of the sludge and the hydraulic characteristics of the clarifier control the performance of secondary clarifiers. They acknowledge that density currents induced in secondary clarifiers affect performance unless adequately considered in design. Controlling the impacts of density currents through increased weir length, in-board weirs, and inlet device design are recommended. No data, however, are provided on which to base these design recommendations. Fitch (13, 14) present theoretical arguments that density currents do not affect the performance of clarifiers settling discrete particles. When settling flocculent suspensions, however, he considers depth and detention time major factors in design because of density currents. Fitch and Lutz (15) discuss density currents and propose limiting their impact on performance by reducing all flow velocities in the clarifier so that a condition of density-stabilized stratification would occur. In this situation, clarified supernatant is displaced upward as the higher density feed enters from below. Deep basins with bottom inlets are proposed to create these conditions.

The literature presents two basic approaches for controlling the impact of density currents on performance. One approach prevents their formation with properly designed inlet structures, while the other consists of allowing the density current to form, but then moving the effluent structures away from the density currents or directing the density currents away from the effluent structure.

Inlet Structures - Preventing Density Current Formation

The literature presents attempts to control the effects of density currents on the performance of activated sludge secondary clarifiers by preventing their formation through changes to the inlet structure. Early research on clarifier inlet structures is related to improving the hydraulic characteristics of primary clarifiers. Hubbell (16) presents an inlet for improving the flow distribution in a primary clarifier. The inlet improved performance, but the data does not demonstrate improved flow distribution. Subsequent research by Hubbell (17) discusses the hydraulic characteristics of different inlets developed for a scale model primary clarifier. One of these inlets, constructed at full-scale, improved the hydraulic characteristics and performance of a primary clarifier. Giles (18) discusses different clarifier inlets, but presents no data on their effectiveness.

Anderson (5) is the first to report on attempts to eliminate density currents in activated sludge secondary clarifiers with different inlets. He indicates that none of 25 different inlet baffling arrangements tried could stop the plunge of the influent to the bottom of the tank. One of these inlets is similar to the inlet successfully used by Hubbell (16) on a primary clarifier. It has no affect on the density currents in this activated sludge secondary clarifier. None of the other baffles are described in detail.

Camp (19) claims that with the nominal flow through velocity in the clarifier large enough the density currents will mix with the tank contents and only have a slight affect on the flow pattern. He presents several proposed clarifier designs with shallow depths and inlets near the bottom (19, 20). Introducing the influent near the surface in deep clarifiers is considered to only increase the intensity of the density currents. No performance data is presented to support these claims or validate the proposed designs.

Fitch and Lutz (15) state that dispersing the velocity of the influent flow stream is critical for establishing the density stabilized basin as discussed above. They discuss the problems of converting the influent velocities to random turbulences and then dissipating these turbulences in the feedwell structure. A tangentially fed velocity dispersing feedwell is described, but no data on its performance is presented. Skirdov, et al. (21) discuss the advantages of introducing mixed liquor at the bottom of a circular clarifier through a rotating bottom distribution device.

Crosby (6) modifies the inlet baffles of a full-scale rectangular clarifier in an attempt to eliminate the density currents thought to be affecting its performance. Several configurations of the baffle do not significantly change the flow patterns in the clarifier.

Stukenberg et al. (8) consider it unlikely that centerwell design will ever eliminate the circulation flow pattern in clarifiers. Centerwells are considered critical to the uniform distribution of flow across the clarifier's floor, however, and may minimize the velocity of the circulation flow. He reports on a trend to minimize the diameter and depth of centerwells to reduce costs which has had an impact on performance.

Parker (9) and Stukenberg et al. (8) consider flocculation important to the performance of activated sludge secondary clarifiers. Parker (9) discusses the relationship between particle size distribution in the effluent, flocculation, and clarifier performance. He states that opportunities for flocculation are limited in conventional clarifiers because most flocculation occurs in the centerwells where detention times are short.

Porta (22) discusses the inlet modifications to 200 foot diameter peripheral feed peripheral overflow activated sludge secondary clarifiers. The original inlets, which introduce the mixed liquor two feet from the bottom, disrupt the sludge blanket and limit the hydraulic capacity. Raising the inlets above the sludge blanket significantly increases the hydraulic capacity of the units.

Preventing Density Currents From Affecting Performance

Several researchers have developed alternatives to prevent density currents, once they have formed, from affecting the performance of activated sludge secondary clarifiers. Gould (91) suggests movement of the effluent structures on rectangular clarifiers towards the influent end of the basin. This is an attempt to move the effluent structure away from the influence of the density current rebounding off of the end wall of the clarifier and the high upward velocities. Anderson (5) discusses the use of in-board weirs on circular clarifiers for the same reasons. Graber (23) concurs with these findings. Stukenberg et al. (8) and Parker (9) consider in-board weirs effective for preventing density currents from affecting circular clarifier performance. Recent trends are noted of moving the in-board weirs towards the tank's periphery because of lower weir loading requirements and cost considerations.

Crosby (6) demostrates two different approaches for preventing density currents from affecting the performance of circular clarifiers. One is a baffle placed at mid radius extending from the floor of the clarifier to mid depth. The baffle is supported by and rotates with the sludge removal mechanism. Measurement of the flow patterns shows that the density current breaks up at the baffle with a 38% improvement in effluent total suspended solids. The second approach consists of a baffle located at the periphery of the clarifier 1.5m (4.9 ft) below the effluent weirs. It slants at a 45 degree angle to prevent solids deposition. Measurement of the clarifier's flow pattern with the baffle shows that the density current deflects away from the effluent structure with a 38% improvement in performance. Stuckenberg et al. (8) use a similar approach by placing a horizontal baffle 610mm (24.0 in.) long directly below the effluent weirs. They show this clarifier producing an average effluent of 7 mg/l total suspended solids.

PROJECT PURPOSE

The literature on activated sludge secondary clarification shows that though a uniformly distributed flow may be desirable these conditions are not achieved in full-scale clarifiers. Most activated sludge secondary clarifiers have flow patterns that consist of a current along the bottom which rebounds

off the wall and recirculates back towards the inlet. Density differences between the influent mixed liquor and the contents of the clarifier cause the formation of these currents.

These density currents can affect performance by transporting solids towards the clarifier's effluent structure. The literature presents two different approaches to prevent this solids loss. One approach prevents the formation of the density currents in the clarifier and the second keeps the effluent structure out of the path of the density current.

Research indicates that several options exist for keeping the density currents away from the clarifier's effluent structure. Properly placed in-board weirs have been proposed and three different baffling techniques demonstrated.

None of the research demonstrated any inlet structure that could prevent density current formation. Several researchers proposed that properly designed inlet structures would prevent density current formation, but none was ever proven effective at full scale. Generally, there is a limited amount of research on clarifier inlets.

This project evaluated, at full-scale, an inlet designed to uniformly distribute the influent flow and prevent density current formation. If this inlet, called the Multi-Port Distributed Inlet, had been successful, design engineers would have had another option available to prevent density currents from affecting activated sludge secondary clarifier performance. They could have then selected the least cost option for their particular application.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

1. The Distributed Inlet evaluated in this project could not create the optimum hydraulic conditions required by clarification theory and clarifier design guidance of a uniformly distributed flow in both the horizontal and vertical direction with no short-circuiting.

2. Introducing the influent mixed liquor flow too deep in the clarifier fluidized the sludge blanket resulting in unstable clarifier performance.

3. Creating a uniformly distributed flow pattern in full-scale activated sludge secondary clarifiers through modifications to the inlet structure may be impossible because of the inherent tendency of the activated sludge to form density currents within the clarifier.

SECTION 3

MATERIALS AND METHODS

DESCRIPTION OF TESTING FACILITY

The Stamford, Connecticut, Water Pollution Control Facility is a 757,000 m^3/d (20.0 mgd) secondary activated sludge treatment facility built in 1976. A flow diagram of the plant is shown in Figure 1. Aeration is provided by 2-speed, mechanical, surface aerators in each of 8 aeration basins. The plant influent is primarly domestic with about 15% industrial contribution. The average 5-day biochemical oxygen demand (BOD_5) is 150 mg/L and total suspended solids (TSS) is 110 mg/L. Sludge is processed through belt filter presses, dried in a rotary kiln using waste heat from a refuse incinerator and then burned in that incinerator. A post-lime stabilization system is used when the incinerator is inoperable.

Each of the two secondary clarifiers are 39.6m (130ft) in diameter with a 4.0m (13ft) side water depth. The influent enters from below the tank up through the center column and out ports located on the column. Velocity is dissipated by means of a feedwell 5.5m (18ft) in diameter and 1.83m (6.0ft) deep. The effluent overflows v-notched weirs located around the periphery of the tank and into a discharge pipe from the effluent launder.

These clarifiers shown in Figure 2 are equipped with a rapid sludge removal system. The sludge from the bottom of the tank is continously removed by suction through 10 separate 254mm (10.0in.) diameter pipes located 5 on each side of the rake arm mechanism. It is then directed to a sludge collection box that surrounds the top portion of the inlet column directly above the inlet ports. From the collection box, the sludge flows back down a concentric pipe within the inlet column where it is removed through the botton of the clarifier and returned to the aeration basins.

FLOW MEASUREMENT AND CONTROL TECHNIQUES

Underflow Measurement

Underflow was measured by magnetic flow meters installed on the return activated sludge lines from each of the clarifiers. In addition, a controlled blanket level was maintained in each unit.

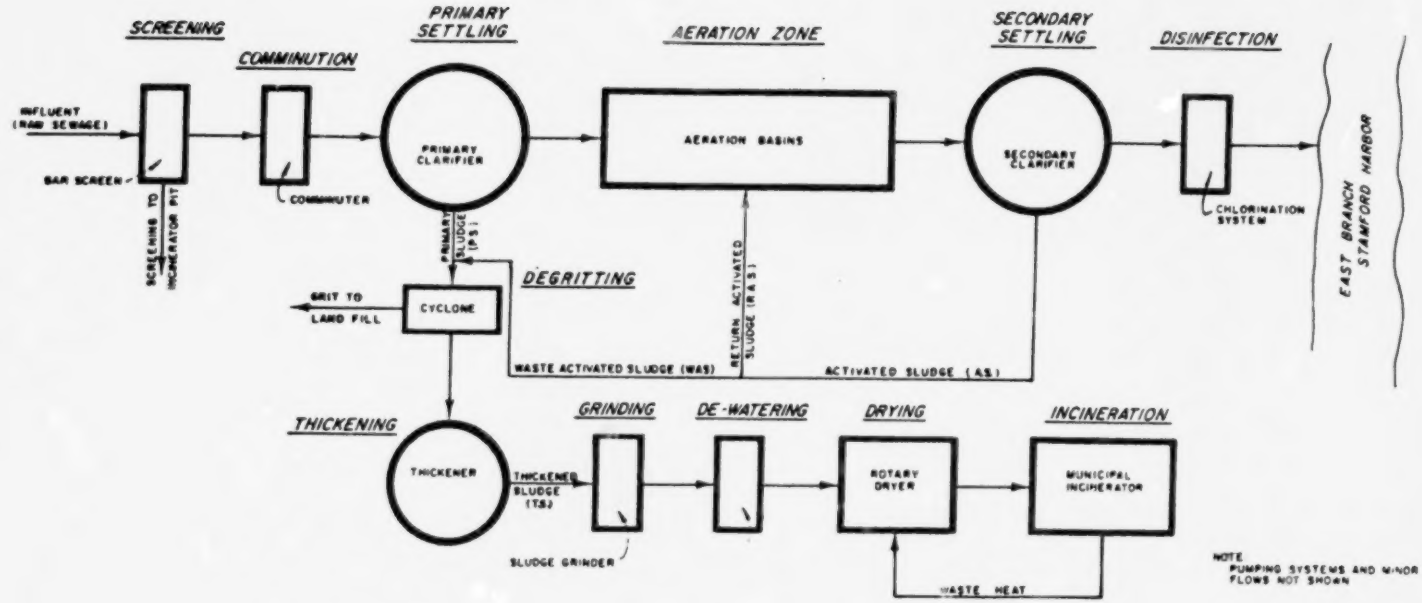

Figure 1. Flow Schematic of the Stamford, Connecticut Water Pollution Control Facility.

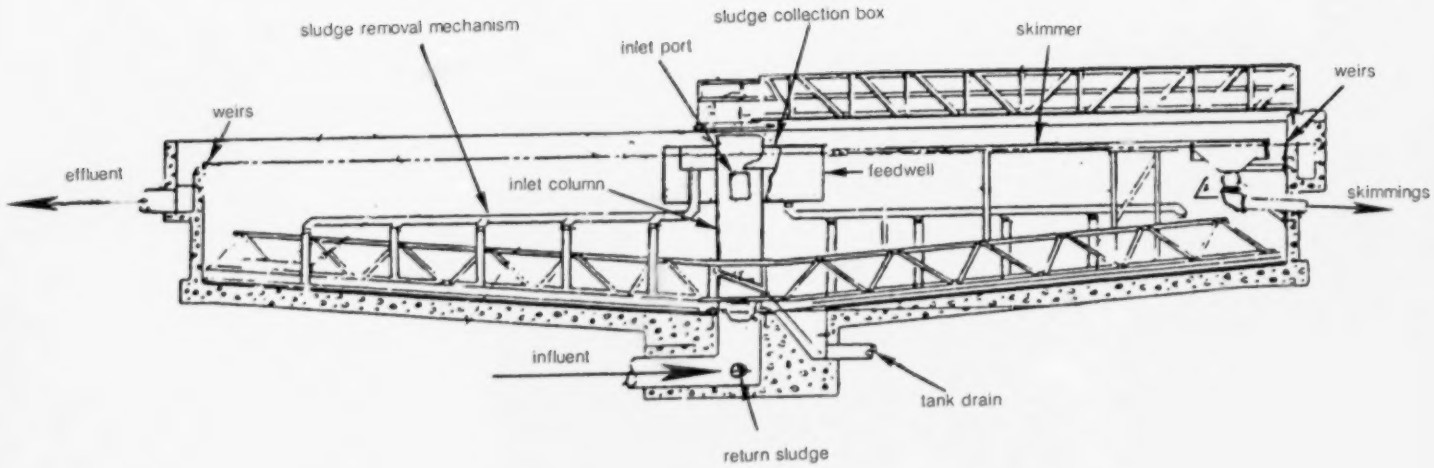

Figure 2. Plan view of the secondary clarifiers at the Stamford, Connecticut Water Pollution Control Facility.

Overflow Measurement

A capacitance surface level gauge, specially designed and constructed by Crosby and Associates for this project, was the overflow measurement device. The instrument consists of an R.F. oscillator, a saturated push-pull amplifier, a transformer and a voltage doubler/filter circuit. The amplifier drives the mercury filled Pyrex[R] probe. The transformer output is proportional to the probe immersion. Sensitivity is field adjusted to 0.04647 volts per mm (1.1803 volts/in.). At the design hydraulic loading of 378,000 m^3/d (10.0 mgd) 45,000 m^3/d (1.19mgd) is equivalent to .25mm (0.1 in.) of surface elevation. Control sensitivity is +0.01 volts, or 0.203mm (0.008 in.). Thus, at design overflow rate, the system is able to control overflow to +3590m^3/d (+0.095mgd) or 1%. Although the Pyrex[R] and mercury probes were suspended in the clarifiers between the scum baffle and weir in a very sheltered location, wind waves were sensed and the probes were subject to fouling by floating material and algae. Additionally, both probes had to be cleaned at the same time, to minimize errors due to differential fouling. Since this project only required equal overflow from each unit rather than a precisely determined flow from either, these sensors were satisfactory. Overflow levels were recorded on strip charts. In addition, prior to the start of the project, the weirs on both clarifiers were leveled to insure that no short-circuiting was occurring.

Overflow Control

Voltage outputs of the two level gauges were fed to a differential amplifier with a gain of 3. This differential amplifier integrated the signals to smooth the effects of small wavelets which were sensed by the level gauges. The amplified differential signal was fed to inverting and non-inverting amplifiers which had gains of 167, and then to logic which, if +0.03 volts or greater were sensed, triggered a series of three second pulses every 70 seconds. The three second pulses drove a relay which presents the plus or minus error signal to the valve actuator located on the influent gate to the clarifier, instructing it to open or close as required. During the intervening seventy seconds, clarifier surface level changes were sensed by the level gauges and the control integrator.

Flow Calibration Procedure

The level gauges for the overflow measurement equipment were calibrated by a dye dilution method using mass balance procedures. Neglecting the very small additional flow rate due to the dye injection, it is clear that

$$q_i C_i = Q_o C_o$$

where q_i = tracer dye injection rate
C_i = concentration of injected dye
Q_o = clarifier effluent flow rate
C_o = concentration of dye in the effluent

Rhodamine WT is injected at a constant rate into the effluent trough, at a location which maximizes mixing. The quantity, q_i, is measured before and

after sampling to insure a constant dye flow rate. Additionally, the specific gravity of the dye solution is measured using a pycnometer at three temperatures within $\pm 10^{0}$ of the ambient temperature to determine accurately the initial dye concentration.

Polyproplene sampling hoses are placed into the effluent trough. After a 10 minute dye injection period, effluent is pumped through these hoses with sampling pumps into a one gallon container for a prolonged period to ensure good mixing. This procedure smooths any variability of dye concentration which might exist from incomplete mixing in the trough. Two replicate samples are taken at one minute intervals from the container and the concentration of dye measured with a fluorimeter. Simultaneously, level gauge output voltage readings are recorded.

A one gallon sample of effluent is taken from the clarifier and a known quantity of dye is added as the calibration standard for the fluorimeter. A second standard is prepared which is diluted with tap water to a concentration close to that in the effluent. The accuracy of the procedure is not increased by making this concentration exactly equal to the effluent, therefore it is recommended that the concentration only be close to that of the effluent. The difference between the value read from the fluorimeter with this standard and the value obtained from the first calibration is a background correction due to interference from the wastewater. Clarifier flow, Q_o, is calculated by dividing $q_i C_i$ by the sample fluorescence minus the background correction.

CLARIFIER PERFORMANCE SAMPLING AND ANALYTICAL TECHNIQUES

Sampling was done in each clarifier using automatic, sequential samplers. A flow-proportioned, composite sample was made up each day from the 24 (one per hour) discrete samples. Total suspended solids (TSS) concentration was determined on each sample and used to evaluate clarifier performance. Sludge blanket depths were monitored on a trice daily basis. A sludge blanket, light-path indicator was used to measure the depth from the water surface to the liquid/solid interface. In addition, food to micro-organism ratio (F/M), sludge volume index (SVI) and sludge residence time (SRT) were also determined on a daily basis. These were used to correlate clarifier performance to quality of mixed liquor.

All analytical procedures used were from "Standard Methods for the Examination of Water and Wastewater". 15th edition.

CLARIFIER HYDRAULIC ANALYSIS TECHNIQUES

Flow Pattern/Solids Distribution Determination

The Hydraulic characteristics within the clarifiers were determined by using the Flow Pattern/Solids Distribution test developed during previous research (5) to obtain an instantaneous picture of the dye's progress along a radial section of the clarifier. A continuous stream of Rhodamine WT dye is injected downstream of the aeration basins at a rate of 1.32ml/min per $10^{6}m^{3}/d$ (0.5 ml/min per mgd) of clarifier overflow. At least five

stations along the selected radius are sampled simultaneously at no less than five depths. This set of 25 samples, collected in 300-ml BOD bottles, show the progress of dye in the section of the clarifier at that instant. All materials used in this procedure must be of white polyethylene, polypropylene or borosilicate glass to prevent uptake and re-release of the dye.

As soon as the samples are taken, a portion of the clear supernatant is decanted into disposable borosilicate glass cuvettes. The dye concentration in each cuvette is then measured by the fluorimeter. The remaining sample in each set is analyzed for TSS. This result is used to determine the instantaneous solids distribution pattern in the clarifier. These data are plotted on individual sectional drawings of the clarifier and contour lines representing equal dye concentration and solids concentration are drawn. The contour plots are then use to interpret the pattern of fluid flow within the clarifier.

Figures 3 and 4 show the results of one of the Flow Pattern/Solids Distribution tests completed for this project. The flow pattern contour plot in Figure 3 shows the relative dye concentration measured within the clarifier. Relative dye concentrations represent normalized actual dye concentrations based on the highest dye concentration measured during the test. Comparisons of normalized dye concentrations between different tests and different clarifiers is considered more meaningful than comparisons of actual dye concentrations. The solids distribution contours, presented in Figure 4, are based on the TSS concentrations measured in the 25 samples collected. The flow pattern contour plots in thie report also show a nominal sludge blanket depth. This represents the average blanket level measured during the particular Flow Pattern/Solids Distributuion Test.

All Flow Pattern/Solids Distribution test results for this report were calculated and plotted by a computer. Note that the vertical scale of the clarifier's dimensions have been exaggerated to provide a clearer distinction between contour lines. Also note that most details of the equipment and structures within the clarifier are not depicted on these drawing for added clarity. The computer calculates and plots contour lines of varying width. Narrow contour lines result from large differences in concentrations between the sampling points. Wide contour lines result from small concentration differences between the sampling points. Wide contours, therefore, represent areas of minimum activity within the clarifier. All points on these wide contours represent points of essentially equal concentration. Narrow contours then represent areas of relatively intense flow.

SECTION 4

RESULTS AND DISCUSSION

BACKGROUND EVALUATION OF THE CONTROL CLARIFIER

All evaluations of the Distributed Inlet for the project were based on comparisons against Stamford's secondary clarifier number 2 with the original inlet structure (Figure 2) which served as the control. The first step of this project was to perform a Flow Pattern/Solids Distribution test on the control clarifier. This was intended to show the background hydraulic characteristics of the Stamford clarifiers. Changes in the hydraulic characteristics with the Distributed Inlet installed in Stamford's secondary clarifier number 1 were then to be compared against these results.

Table 1 presents the conditions for this series of Flow Pattern/Solids Distribution tests and Figures 3 and 4 show the results.

Table 1. CONDITIONS FOR FLOW PATTERN/SOLIDS DISTRIBUTION TEST 1 - CONTROL CLARIFIER

Parameter	Clarifier # 2
Eff. TSS, mg/L*	19
Overflow, m^3/m^2-d	32
Underflow, %	26
Average MLSS, Mg/L	2680
Average SVI	115
Underflow TSS, Mg/L	6500
Blanket depth, m+	3.7
Test Time, min	19.5

* 24-hr flow-proportioned, composite on each clarifier
\+ at time of test

The flow pattern (Figure 3) shows the high velocity density currents considered typical for this type of clarifier based on the literature. These currents traveled below the deepest sample at 3.80 m (12.5 ft) emerging near the periphery then moving towards the wiers.

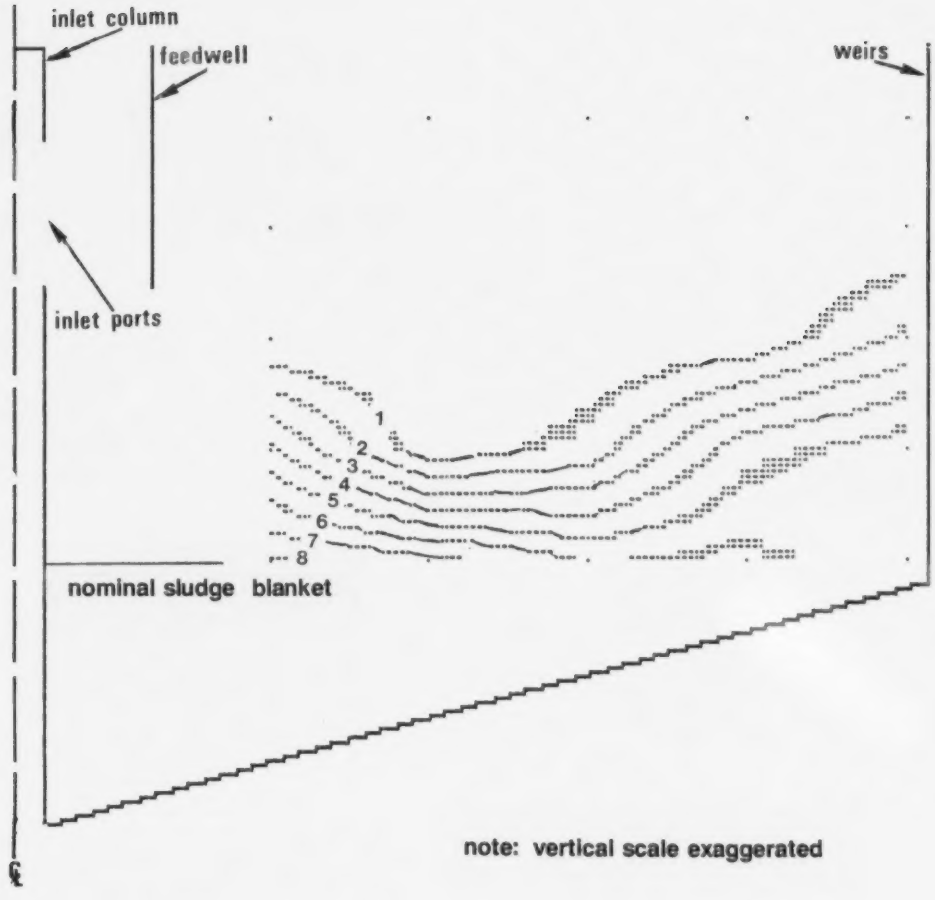

Figure 3. Radial distribution of relative dye concentrations in Stamford secondary clarifier #2 with original inlet structure 19.5 minutes after start of continuous dye injection.

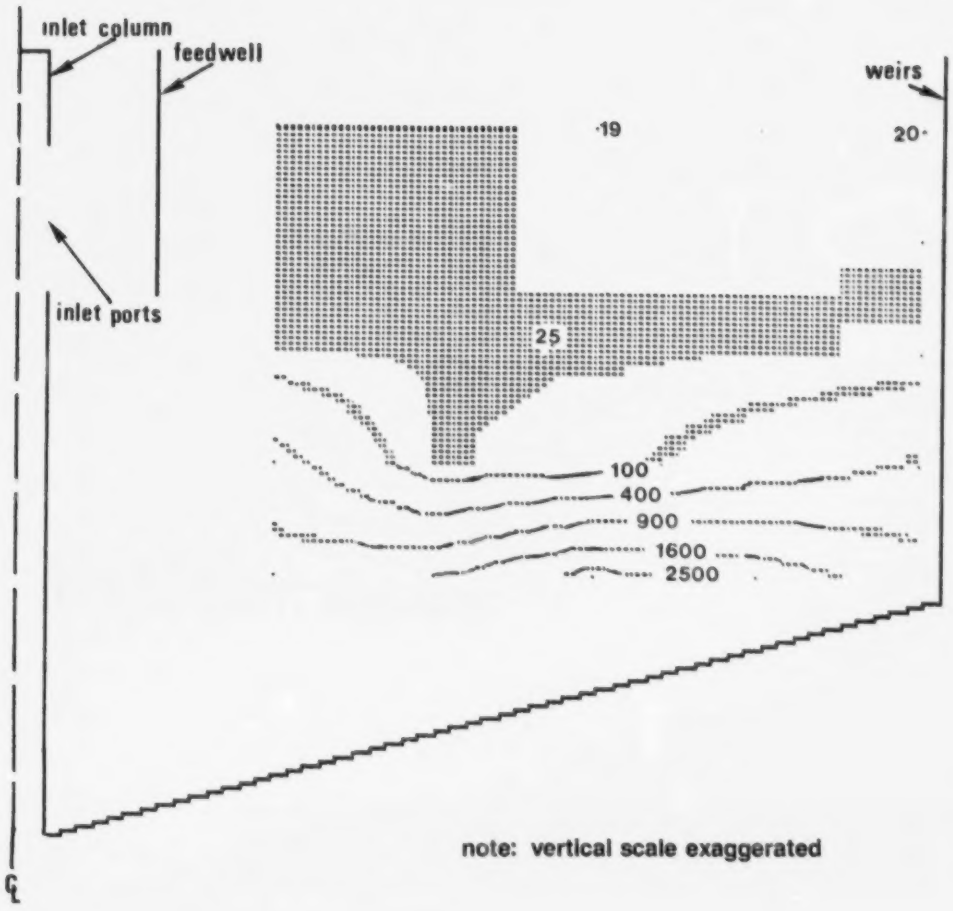

Figure 4. Radial distribution of TSS in Stamford secondary clarifier # 2 with original inlet structure

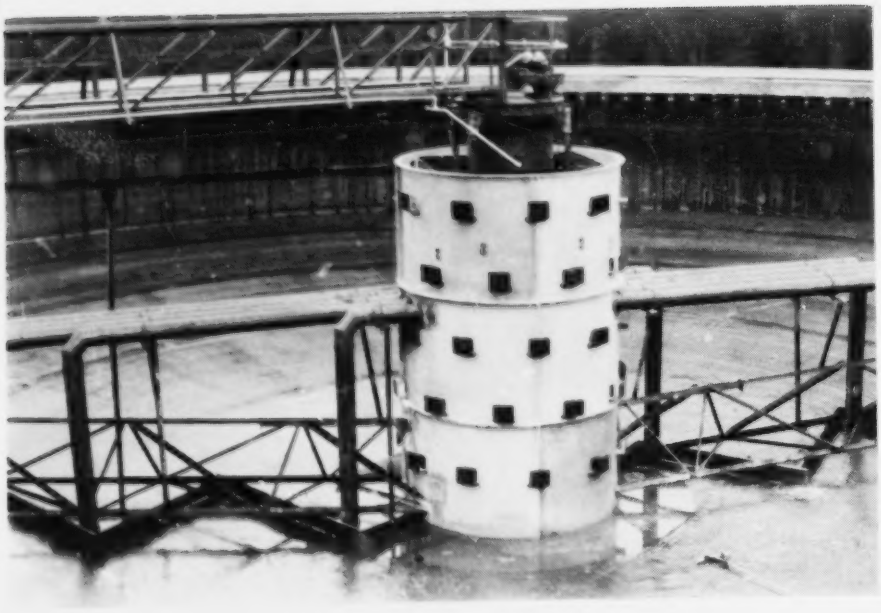

Figure 5. Multi-Port Distributed Inlet - Original Design

EVALUATION OF THE MULTI-PORT DISTRIBUTED INLET

Multi-Port Distributed Inlet Description - Original Design

Figure 5 shows the Multi-Port Distributed Inlet designed to provide an evenly distributed flow throughout the entire depth of the clarifier. It was 3.34 m (11.0 ft) in diameter and extended the full depth of the clarifier. The area of each port was determined on the basis of providing an opening large enough to prevent shearing of the mixed liquor floc, but small enough to achieve sufficient head loss to obtain equal distribution. These requirements resulted in ports which were 203 mm (8.0 in.) square. The total area of the 48 ports was equal to the combined area of the 4 inlet ports located in the original center inlet column of the clarifier. Each port was equipped with a 254 mm by 304 mm (10.0 in. by 12.0 in.) metal deflection baffle. These baffles were intended to direct the flow upward, changing the direction of the flow so as to dissipate the energy of the mixed influent liquor.

Figure 6 shows the anticipated flow pattern that the Distributed Inlet was supposed to create in Stamford's secondary clarifier # 1. Note how the lines of equal relative dye concentration were to radiate from the Distributed Inlet towards the weirs and be evenly distributed throughout the depth. This flow pattern represents the optimum hydraulic conditions in a clarifier from the literature discussed previously, where the flow through the clarifier is uniformly distributed both horizontally and vertically with no short circuiting. If the Distributed Inlet created this flow pattern and/or demonstrated improved performance over Stamford's secondary clarifier # 2 with the original inlet structure, the Distributed Inlet would be considered successful.

Evaluation of the Multi-Port Distributed Inlet - Original Design

The Multi-Port Distributed Inlet was installed in Stamford's secondary clarifier # 1 during November, 1982, after removing the existing feedwell and support brackets. The inlet was installed in sections and field-modified to totally seal the areas around the rake mechanism and sludge return pipes. A metal plate was bolted across a portion of the sludge sump at the bottom of the clarifier to prevent the secondary sludge from flowing through the sump instead of the sludge return pipes.

Evaluation of the Distributed Inlet began in February 1983 with measurement of the flow pattern/solids distributions under the conditions presented in Table 2.

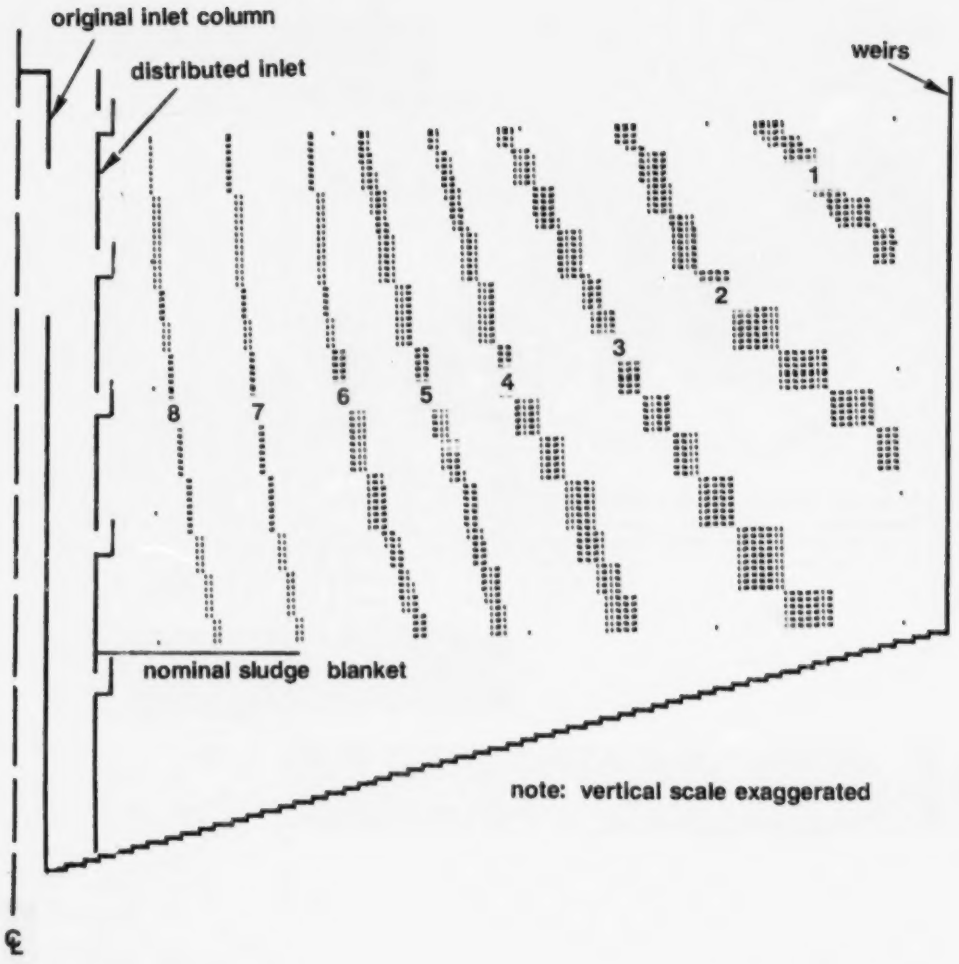

Figure 6. Anticipated radial distribution of the relative dye concentrations in Stamford secondary clarifier # 1 with Distributed Inlet

Table 2. CONDITIONS FOR FLOW PATTERN/SOLIDS DISTRIBUTION TEST 1 - DISTRIBUTED INLET

Parameter	Clarifier # 1
Eff. TSS, mg/L*	31
Overflow, m^3/m^2-d	35
Underflow, %	24
Average MLSS, Mg/L	2640
Average SVI	107
Underflow TSS, Mg/L	6100
Blanket depth, m+	3.2
Test Time, min	19.0, 38.0

* 24-hr flow-proportioned, composite on each clarifier
+ at time of test

Results of Test I, shown in Figure 7 and 8, indicated that the anticipated uniformly distributed flow was possibly created near the inlet, but that it dissipated when high velocity density currents formed further out in the radius of the clarifier. The net effect was that the flow pattern in the clarifier with the Distributed Inlet was similar to that found in the control clarifier.

The second test was designed to determine if increasing the hydraulic loading to the clarifier would allow the uniformly distributed flow, seen near the inlet in Test I, to proceed further out into the radius of the clarifier after leaving the Distributed Inlet. For Test II flow to the clarifier was increased 54% and a second Flow Pattern/Solids Distribution test completed under the conditions presented in Table 3.

TABLE 3. CONDITIONS FOR FLOW PATTERN/SOLIDS DISTRIBUTION TEST II - DISTRIBUTED INLET

Parameter	Clarifier #1
EFF TSS, mg/L*	29
Overflow, m^3/m^2-d	54
Underflow, %	23
Average MLSS, mg/L	2740
Average SVI	100
Underflow TSS, mg/L	7650
Blanket depth, M+	3.5

* 24 hr. flow-proportioned composite sample
+ at time of test

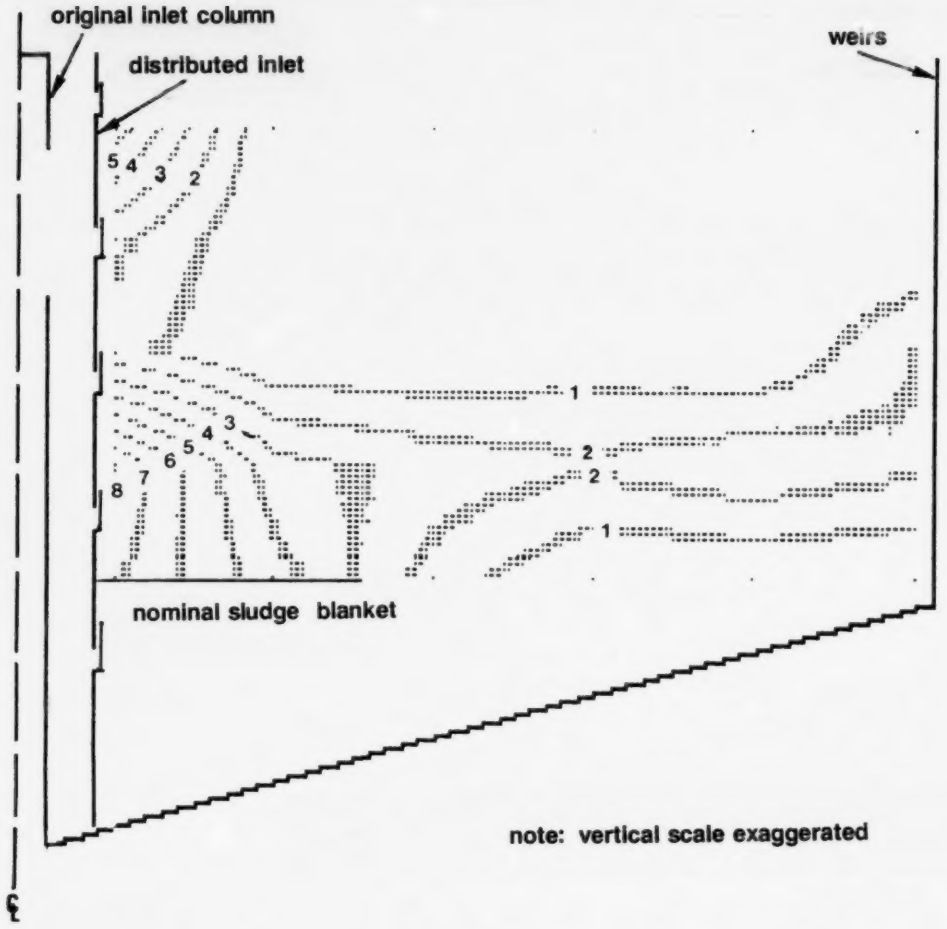

Figure 7. Radial distribution of the relative dye concentrations in Stamford secondary clarifier # 1 with Distributed Inlet, 19.5 minutes after start of continuous dye injection, Test I

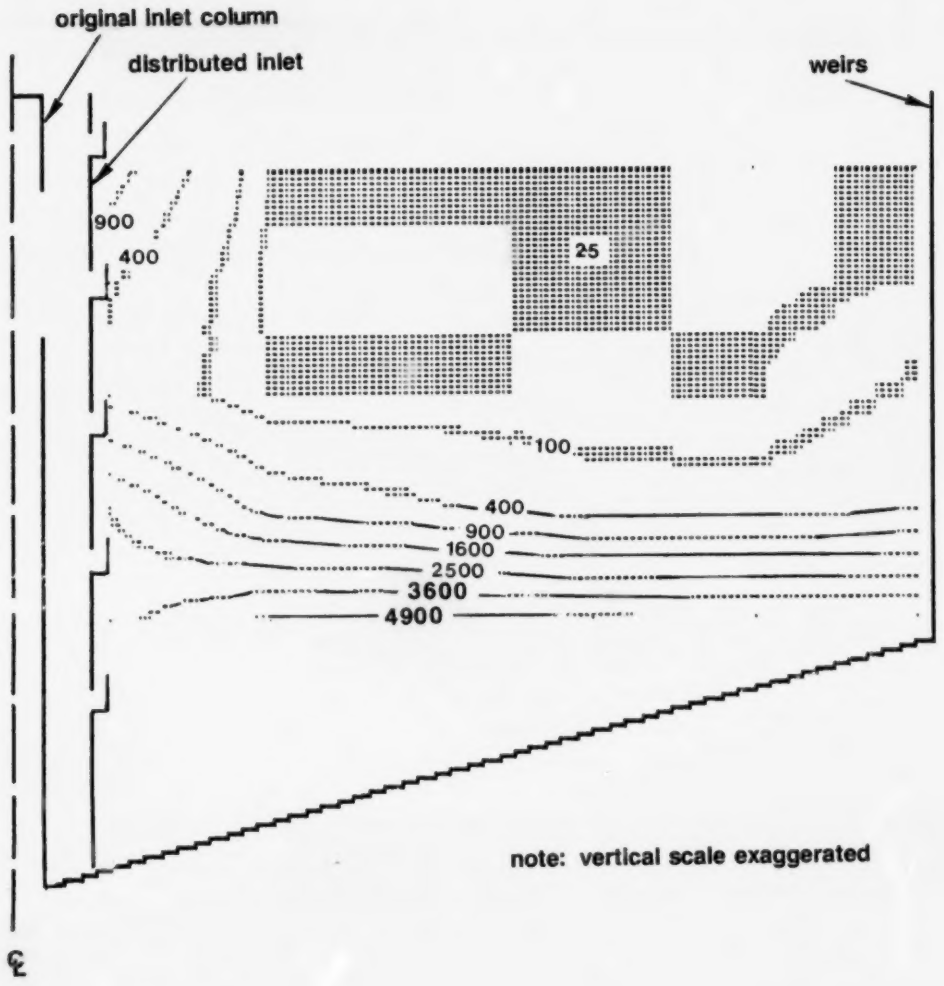

Figure 8 Radial distribution of total suspended solids (TSS) in Stamford secondary clarifier # 1 with Distributed Inlet, Test I

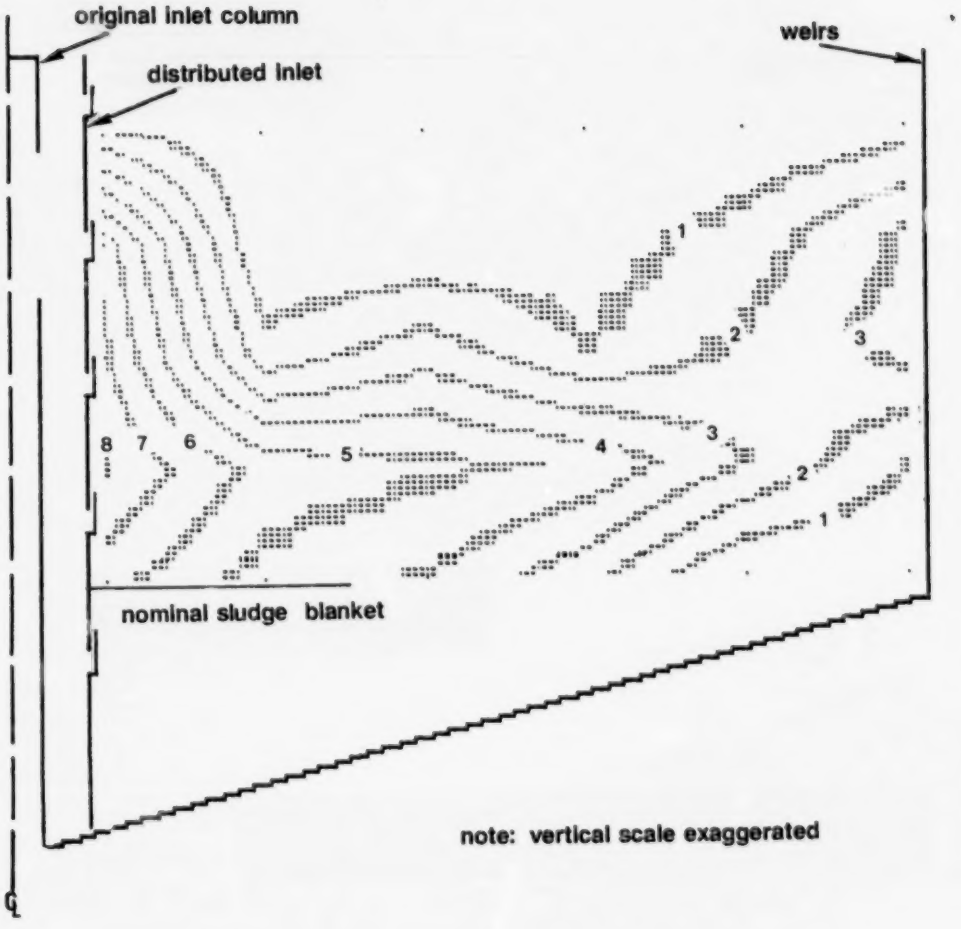

Figure 9. Radial distribution of the relative dye concentration in Stamford secondary clarifier # 1 with Distributed Inlet, 19.0 minutes after start of continuous dye injection, Test II

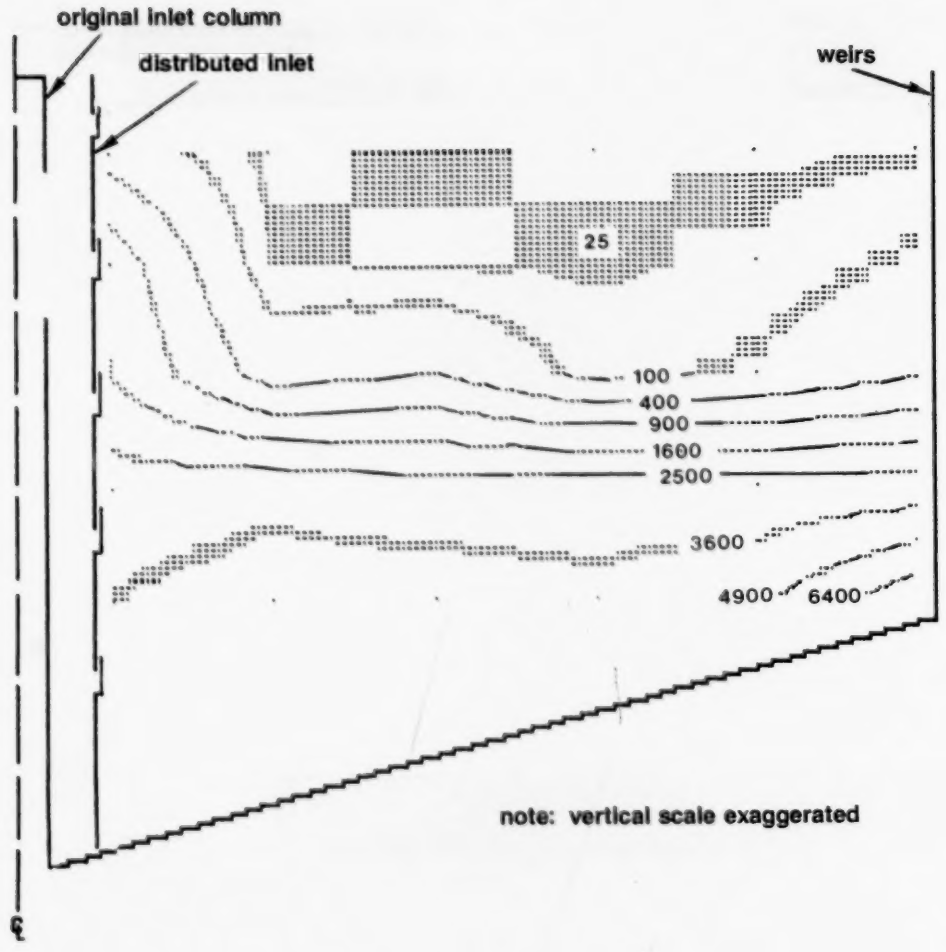

Figure 10. Radial distribution of TSS in Stamford secondary clarifier # 1 with Distributed Inlet, Test II

Figure 9 and 10 show the results of Test II. The flow pattern (Figure 9) showed no indication of a uniformly distributed flow, but only intense high velocity density currents proceeding from the inlet to the periphery of the clarifier then proceeding upwards towards the wiers. Solids within the clarifier (Figure 10) were more dispersed than Test I. This was indicated by the higher concentration contours being located further from the bottom and the 25 mg/L contours much closer to the surface than found in Test I (Figure 8). Also note the higher solids concentrations (6400 mg/L) nearer the periphery than found in Test I. Overall, the combination of the higher hydraulic loadings are the Distributed Inlet resulted in poorer hydraulic characteristics on the Stamford secondary clarifier # 1 than the control clarifier.

It is important to note that the results of the Flow Pattern and Solids Distribution tests represent a "snap-shot" in time. They show what is occurring only at the moment the samples are being taken and do not indicate the long-term effects of the inlet on clarifier performance. In order to show the actual effect on the clarifier's performance characteristics of the inlet, a side-by-side comparison of the performance of the two clarifiers was completed over an eight month period. Typical performance data from a portion of this period is given in Table 4.

These data were analyzed using a paired "t" test. The paired "t" test statistically analyses two sets of data to determine if the difference between the data sets is significant. In this case, it was used to mathematically prove that the observations and conclusions being made about the Distributed Inlet were accurate.

A "t" statistic was calculated from the difference in TSS concentrations between the clarifiers. This calculated value (3.414) was compared to a value obtained from a "t" table for the 95% confidence limit (2.040). Since the calculated "t" value was greater than the value for the 95% confidence limit, it could be concluded that the modified unit produced effluent with higher suspended solids. This confirmed the observations and conclusions made about the inlet from the analytical data.

Since unusually high values of TSS were measured on March 8-11, these data were excluded and a second paired "t" test was done. The recalculated "t" statistic was 5.273 as compaired to a value of 2.052 for the 95% confidence limit. This confirmed that the clarifier with the Distributed Inlet performed worse than the other clarifier with the original inlet structure.

As discussed previously, Figure 9 shows a high concentration of solids (6400 mg/L) deposited along the peripheral wall of the clarifier. This deposit created serious operational problems and was possibly the prime cause of the poor effluent quality from the clarifier with the Distributed Inlet. The outer most sludge return pipes are not designed to remove the quantity or concentration of material accumulated in this deposit. Therefore, the sludge

TABLE 4. SIDE-BY-SIDE CLARIFIER PERFORMANCE DATA

Date (1983)	Blanket Depth (m)	Overflow Rate (m^3/m^2-d)	F/M	SVI	SRT (days)	Effluent TSS (mg/L) #1	#2
2/15	3.4	34	0.21	113	5.3	54	44
16	3.5	38	-	113	4.7	42	26
17	3.0	35	0.25	106	6.1	26	21
18	3.2	37	-	98	5.9	28	17
25	3.8	38	0.23	98	7.0	13	13
28	4.1	38	0.29	94	6.1	18	12
3/1	3.8	40	0.21	98	5.9	10	12
2	3.4	43	0.27	94	4.0	13	12
3	2.9	41	-	94	4.9	28	13
4	3.8	41	-	97	5.5	21	13
7	4.1	43	0.20	78	5.9	14	12
8	4.0	44	0.25	97	5.2	54	14
9	4.0	46	0.33	96	4.8	49	12
10	4.0	48	-	90	-	126	34
11	3.8	48	-	88	-	83	43
14	3.8	38	0.22	99	6.5	15	16
15	3.7	38	0.27	97	7.1	16	16
16	3.7	35	0.22	95	7.1	15	16
17	-	44	-	96	5.7	18	17
18	3.8	55	-	96	5.4	23	20
21	-	52	0.28	91	3.3	30	19
22	3.7	48	0.36	97	2.9	36	28
8/23	4.0	25	-	136	7.1	20	16
24	3.8	26	0.21	138	6.6	19	12
31	3.8	29	-	108	4.9	17	18
Average/ Std.- Dev.	3.7/0.33	40/0.05	0.25/0.05	100/13	5.6/1	32/26	19/9

could not be removed at a fast enough rate or completely enough to prevent denitrification. A dissolved oxygen profile of the clarifier (Figure 11) showed an oxygen depression at the peripheral wall. Later tests showed that area of the clarifier to be anoxic thus encouraging denitrification. The Nitrogen bubbles apparently formed during denitrification carried the sludge solids up the sidewall and over the effluent weirs.

In addition, observations made around the peripheral weir showed considerable variations in effluent quality. Although the weirs were leveled at the start of this project, it was theorized that "short-circuiting" might be occurring. The weirs were re-leveled and an experiment was conducted to

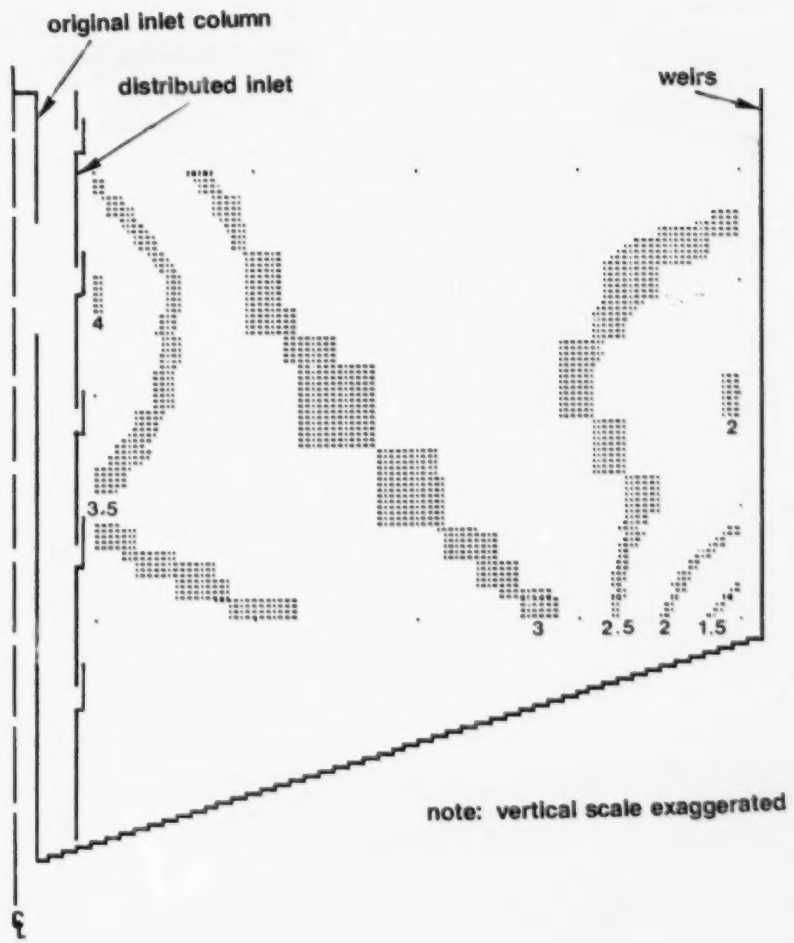

Figure 11. Dissolved oxygen profile in a radial section of Stamford secondary clarifier # 1 with Distributed Inlet

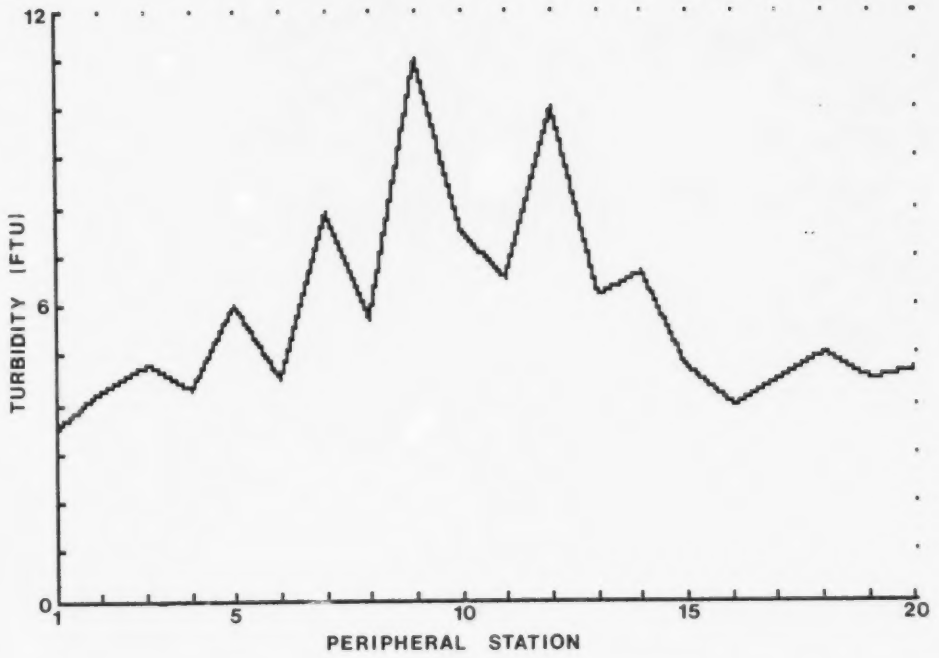

Figure 12. Effluent turbidity levels at the 20 peripheral sampling stations in Stamford secondary clarifier # 1 with Distributed Inlet

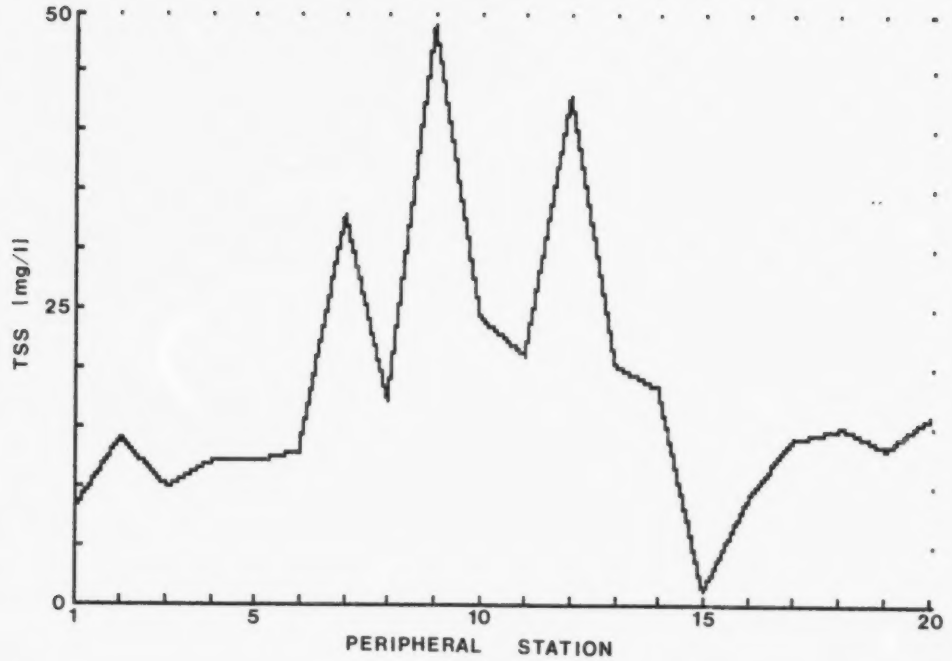

Figure 13. Effluent TSS concentrations at the 20 peripheral sampling stations in Stamford secondary clarifier # 1 with Distributed Inlet

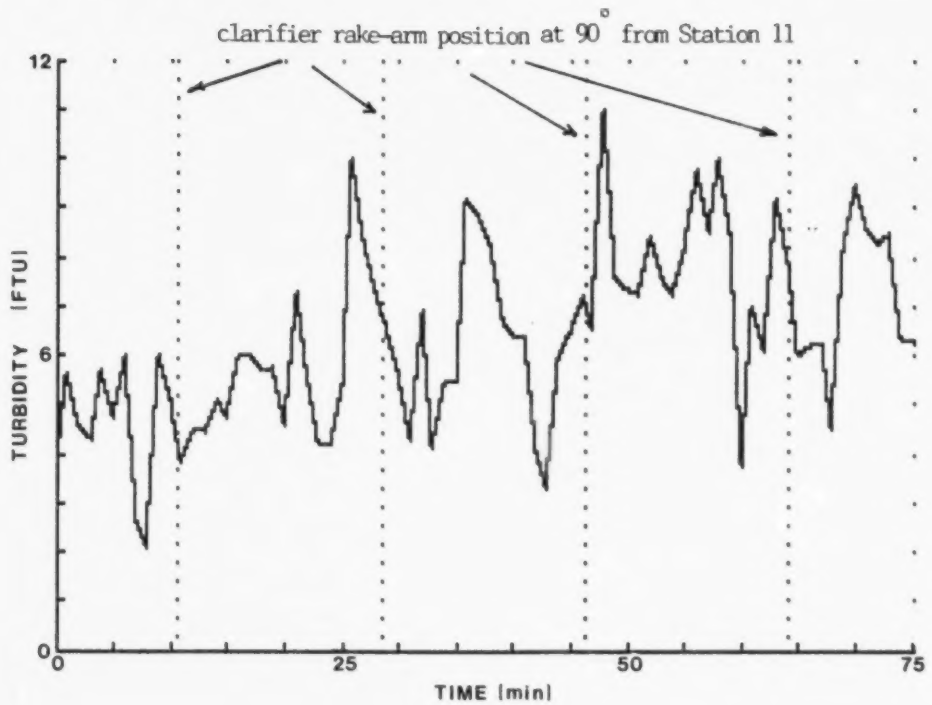

Figure 14. Effluent TSS concentrations versus time at sampling station II in Stamford secondary clarifier # 1 with Distributed Inlet

quantify these observations. Twenty sample points were located at 18 degree intervals around the periphery of the clarifier with Station 1 at the access bridge and Station 11, 180 degrees from the bridge. Samples were taken every 5 minutes at each location for 2.5 hours and then composited. This composite period, four complete rake cycles, was chosen to negate any possible weir-wall solids effects as reported by Crosby (6) in earlier studies. Turbidity and TSS were determined on each of the 20 composited samples. The results, shown in Figures 12 and 13, indicated that the region of poorest effluent quality was at Station 9 and 12.

At the same time these samples were being taken, an additional series of samples were also collected at Station 11 to try to determine if the rake-arm position was influencing the effluent quality. Individual samples were taken at 1 minute intervals for 75 minutes (two complete rake-arm rotation cycles). Turbidity was determined on each of the 75 samples and the results shown in Figure 14. The vertical dotted lines are the rake-arm position 90° away from Station 11 which is the region of greatest rake-arm influence as determined from previous experiments (6). The data showed, however, that the rake-arm position did not appear to influence the solids carryover.

In addition, a 1-liter sample of dye was added to the test clarifier to try to visually track the surface flow pattern. This test was done under the following conditions: overflow rate, $33 m^3/m^2 \cdot d$ (814 $gal/ft^2 \cdot d$) and blanket depth, 4.39m (14.5 ft). The dye was first seen at Station 9, 8.5 minutes after it was introduced into the clarifier. By 11 minutes, dye was seen overflowing all of the periphery except the area between Stations 1 and 5. By 12.5 minutes, dye was overflowing the entire weir. On the surface, however, dye was only visible at the periphery and not over the entire surface. This indicated a very definite density current within the clarifier.

Since the results of these various tests were unique to the Stamford secondary clarifier # 1 and since all other operating parameters in each clarifier were identical, it was concluded that the observed flow-patterns and solids distribution was caused by the Distributed I let. Therefore, to reduce these effects and improve performance two modifications to the Distributed Inlet were evaluated.

Multi-Port Distributed Inlet - First Modification

In the original design of the Distributed Inlet, the upper most row of deflection baffles was used primarily to prevent any surface current formation which might cause short-circuiting within the clarifier. In reviewing the performance data on the inlet, it was theorized that this upper row of baffles might actually be inducing surface currents instead of preventing them. If "short-circuiting" was occurring this might explain why the effluent in some areas of the weir had a higher TSS and turbidity level than others. Therefore, the upper row of baffles were removed. Flow Pattern/Solid Distribution tests were performed on this first modification. The test was performed under the following conditions: overflow rate, $32 m^3/m^2 \cdot d$ (791 $gal/ft^2 \cdot d$) and blanket depth, 4.27m (14.0 ft). The results of these determinations are shown in Figures 15 and 16 and indicate the presence of

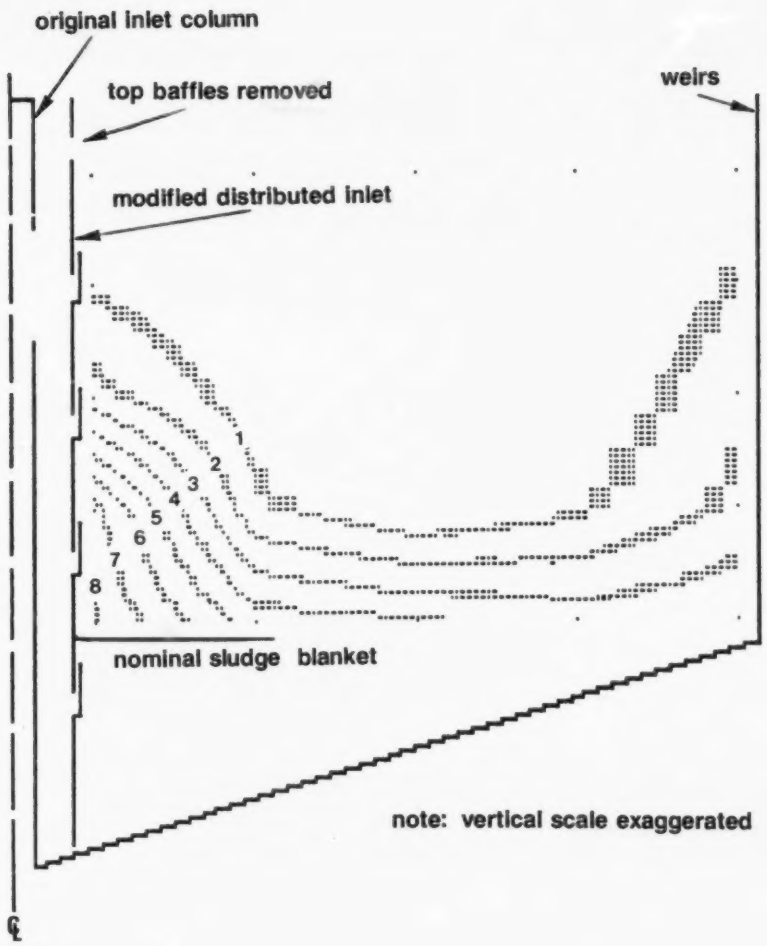

Figure 15. Radial distribution of relative dye concentration in Stamford secondary clarifier # 1 with first modification to Distributed Inlet, 20.0 minutes after start of continuous dye injection

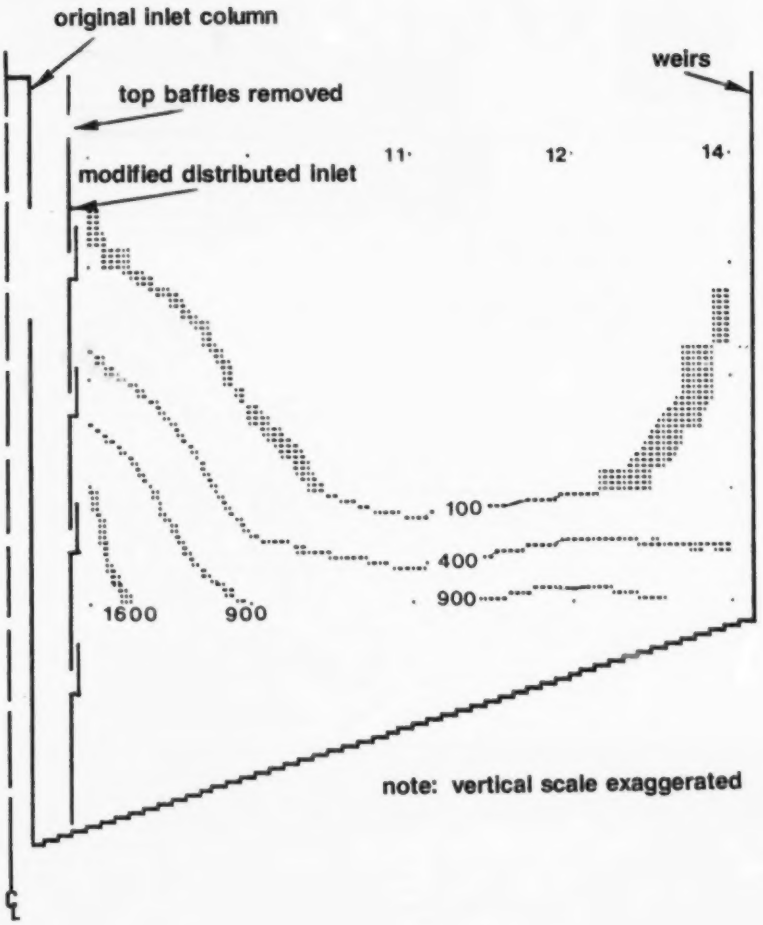

Figure 16. Radial distribution of TSS in Stamford secondary clarifier # 1 with first modification to Distributed Inlet

Figure 17. Multi-Port Distributed Inlet - Second Modification

density currents within the clarifier as before. Furthermore, there was no indication of any surface current formation caused by the removal of the baffles. Thus, these baffles did not appear to influence the flow distribution in the clarifier either negatively or positively.

Multi-Port Distributed Inlet - Second Modification

The second modification to the Distributed Inlet, shown in Figure 17, involved changing the arrangement pattern and the number of ports. The purpose of this modification was to introduce the mixed liquor as near the top of the sludge blanket as possible. Thus, theoretically preventing fluidization of the blanket from those ports which were below the blanket level and preventing formation of density currents due to the upper rows of ports. The upper two rows and the bottom row of ports were closed off. Twenty new ports were added to the second row from the bottom and a new row of 8 ports added 50.8 cm (20.0 in.) above it. Each of the new ports was baffled identically to the existing ones.

Flow patterns and solid distributions were measured within the clarifier after this second modification. The conditions for these tests, shown in Table 5, were similar to those for the other tests on the inlet.

TABLE 5. CONDITIONS FOR FLOW PATTERN/SOLIDS DISTRIBUTION - SECOND MODIFICATION TO DISTRIBUTED INLET

Parameter	Test I	Test II
Overflow, m^3/m^2-d	36	46
Underflow, %	21	16
Average MLSS, mg/l	1670	1395
Average SVI	127	124
Underflow TSS, mg/l	8900	7750
Blanket depth, m*	4.1	4.3

* At time of test

The results from Test I on the modified inlet (Figures 18 and 19) show some similarities to those from Test I of the original version of the Distributed Inlet (Figures 7 and 8). Some possible uniform flow distribution appears near the modified inlet (Figure 18), but dissipates with the formation of a density current as it flows radially towards the periphery of the clarifier. As this flow strikes the wall it flows upwards towards the weirs. The solids distribution within the clarifier (Figure 19) are also similar to those with the original Distributed Inlet, but the modifications to the inlet appears to be more desruptive to the sludge blanket. These results also indicated that the anticipated uniformly distributed flow could not be created in the Stamford secondary clarifier # 1 even with these modifications to the Distributed Inlet.

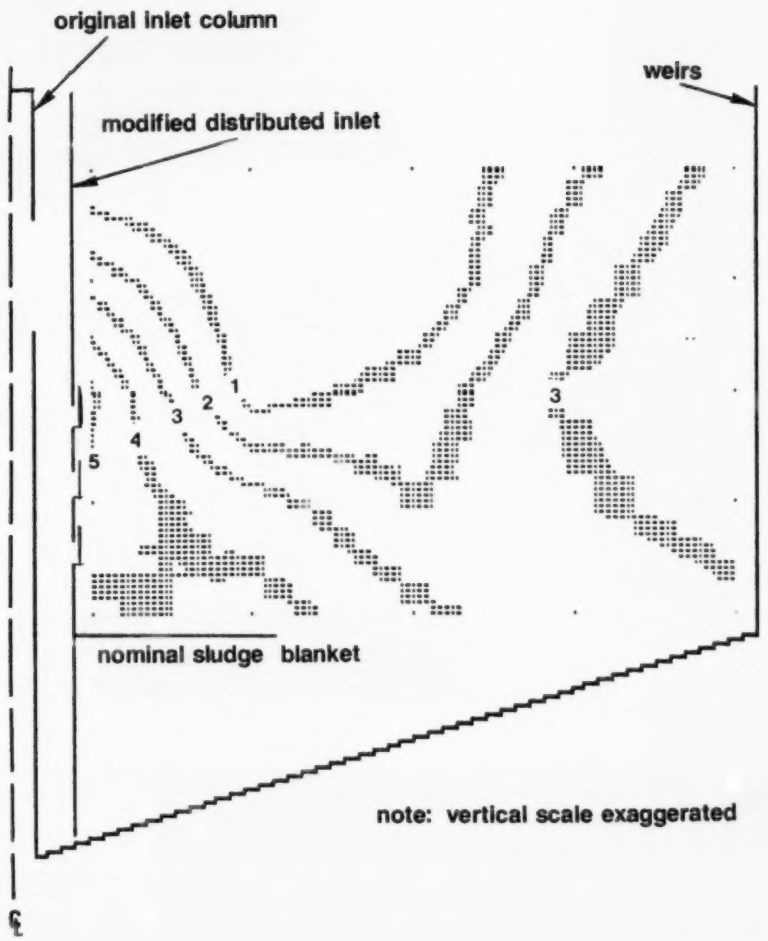

Figure 18. Radial distribution of relative dye concentrations in Stamford secondary clarifier # 1 with second modification to Distributed Inlet, 36.0 minutes after start of continuous dye injection, Test I

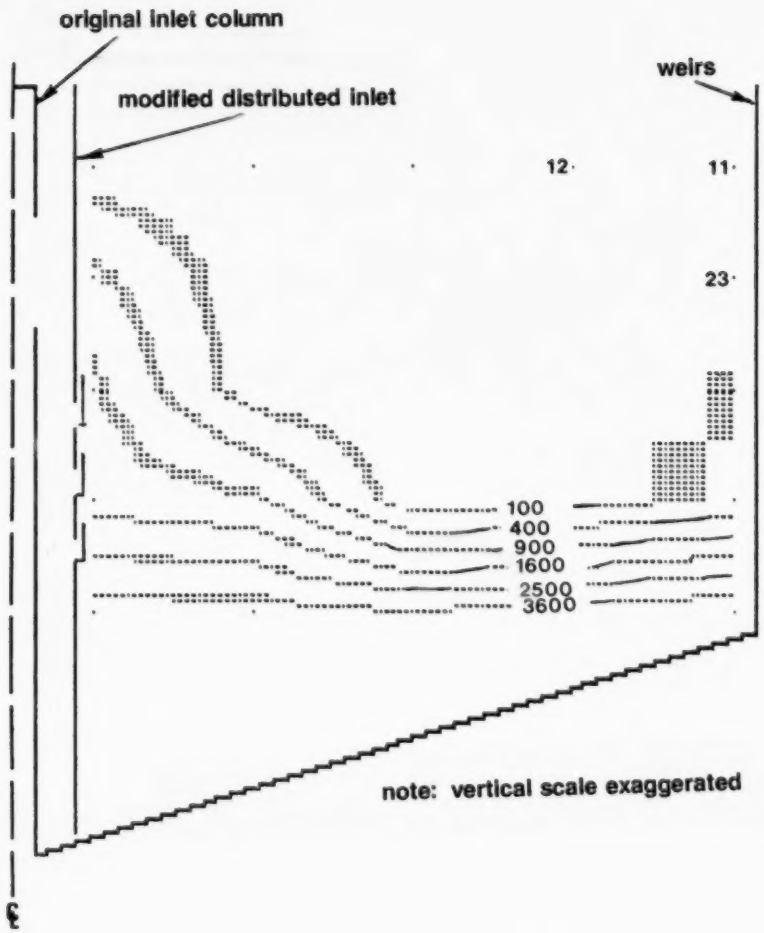

Figure 19. Radial distribution of TSS in Stamford secondary clarifier # 1 with second modification to Distributed Inlet, Test I

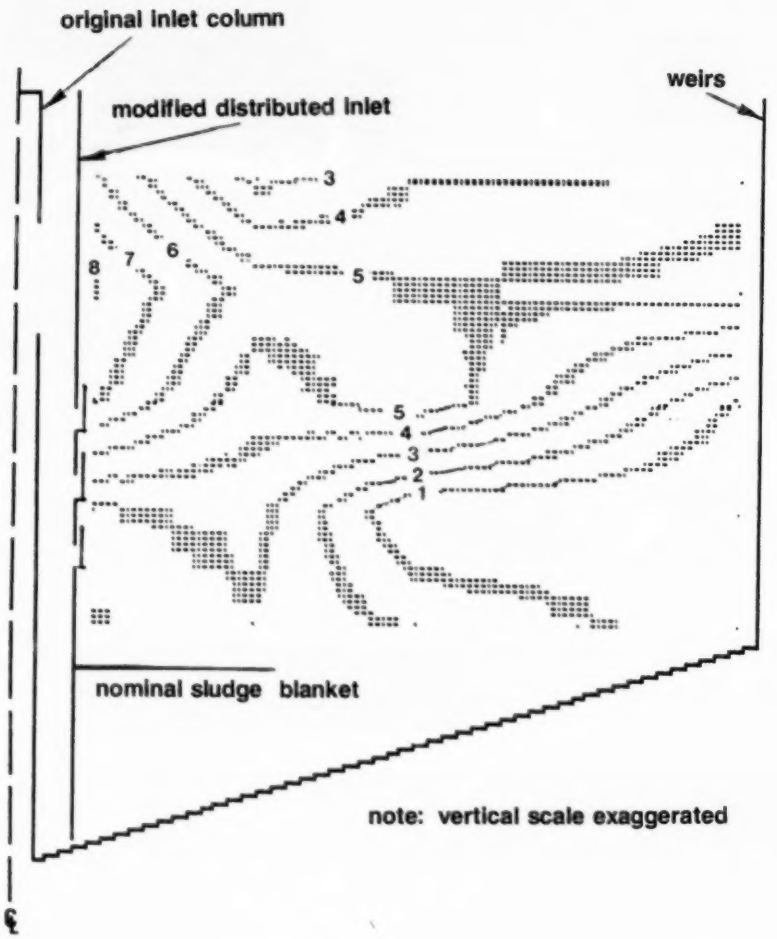

Figure 20. Radial distribution of relative dye concentration in Stamford secondary clarifier # 1 with second modification to Distributed Inlet, 20.0 minutes after start of continuous dye injection, Test II

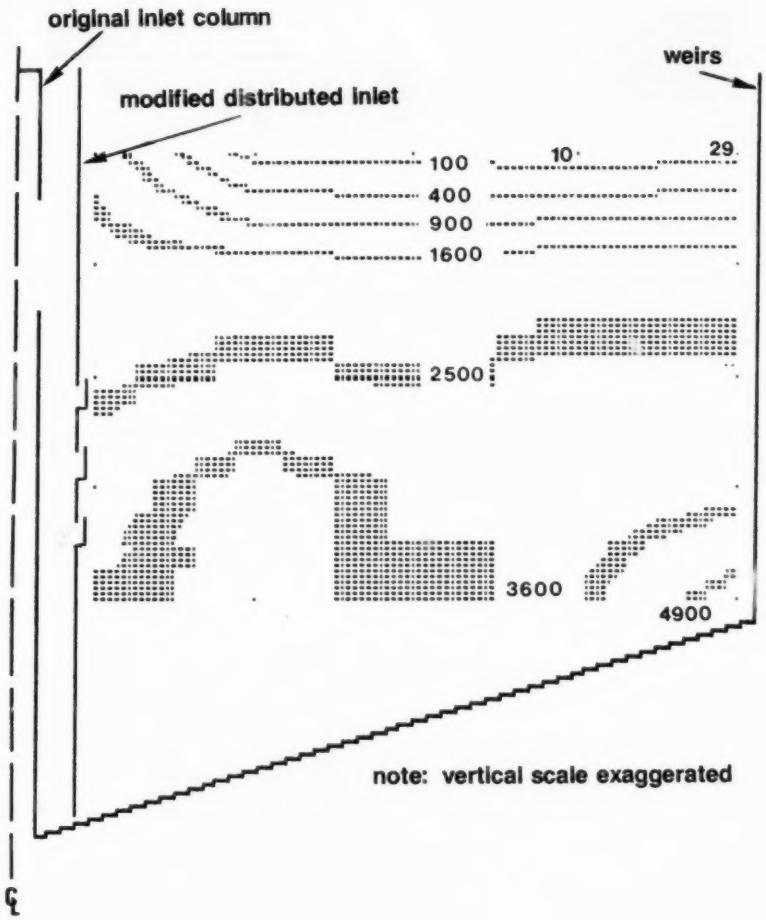

Figure 21. Radial distribution of TSS in Stamford secondary clarifier # 1 with second modification to Distributed Inlet, Test II

For Test II the hydraulic loadings to the clarifier were increased 27%. Figures 20 and 21 show the dramatic results of this change. The flow pattern (Figure 20) indicates intense high velocity currents in the clarifier while the solids distribution (Figure 21) indicates that the sludge blanket has been fluidized and performance severely degraded.

Many problems were encountered throughout the test period such as, weather conditions, mechanical failures and scheduling. These tended to limit the amount of performance data. However, the main cause for the lack of substantial quantities of performance data was the poor performance of the multi-port inlet itself. In order to maintain effluent quality, flows to the modified clarifier had to be continually adjusted. Because of this, several planned experiments which required controlled flows at various rates could not be performed.

For these reasons, no side-by-side comparisons were completed to show differences in performance between the clarifier with the second modification to the Distributed Inlet and the other clarifier with the original inlet structure. The performance of the clarifier after modifying the Distributed Inlet was still obviously worse than that achieved by the other clarifier with the original inlet structure. No further modifications to the Distributed Inlet were attempted.

SUMMARY

The Distributed Inlet evaluated at full-scale in this project could not create the desired uniformly distributed hydraulic conditions in the clarifier at Stamford. The Distributed Inlet caused the clarifier to perform worse than a similar clarifier with a conventional inlet structure. Modifying the Distributed Inlet to introduce the mixed liquor lower in the clarifier only fluidized the sludge blanket and made the hydraulic conditions in the clarifier and its performance worse.

Though the creation of a uniformly distributed flow pattern within an activated sludge secondary clarifier may be theoretically beneficial and required by some state design criteria, it does not appear to be achieved in most full-scale units. Inlet structures appear to have little influence on preventing density current formation which destroys any uniformly distributed flow created by an inlet structure.

These conclusions are based on the results from the project and those reported in the Literature. Inlet structures are critical to good clarifier performance, but probably cannot eliminate the formation of density currents in activated sludge secondary clarifiers.

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